Atmospheric Transport of Mold Spores in Clouds of Desert Dust

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ABSTRACT. Fungal spores can be transported globally in clouds of desert dust. Many species of fungi (commonly known as molds) and bacteria—including some that are human pathogens—have characteristics suited to long-range atmospheric transport. Dust from the African desert can affect air quality in Africa, Europe, the Middle East, and the Americas. Asian desert dust can affect air quality in Asia, the Arctic, North America, and Europe. Atmospheric exposure to mold-carrying desert dust may affect human health directly through allergic induction of respiratory stress. In addition, mold spores within these dust clouds may seed downwind ecosystems in both outdoor and indoor environments.
<Key words: African dust, arsenic, asthma, fungal spores, health effects, mold, public health>

THE DRAMATIC INCREASE in the transport of soil dust across the Atlantic and Pacific oceans during the past 30 yr has been well documented.[1–3] Although geological evidence indicates that African and Asian dusts have been crossing the oceans for eons, the flux of dust has more than doubled since 1970.[4] The timing and increase in volume of African dust flux can be attributed to the ongoing drought in North Africa that began around 1970.[1,5,6] Year-to-year variations in this flux are associated with cyclic latitudinal changes in the North Atlantic Oscillation (NAO), which is a large-scale, multiyear fluctuation in atmospheric pressure between the subtropical high-pressure system located near the Azores in the Atlantic Ocean and the subpolar low-pressure system near Iceland. Positive phases of the NAO—when the system is located at higher latitudes over the North Atlantic—result in increased aridity in the Sahara and Sahel regions of North Africa. These 1- to 3-yr shifts lead to greater dust generation and transport (Fig. 1).[7] On a global scale, regional weather and dust transport are also influenced by a periodic weather phenomenon known as the El Niño Southern Oscillation (ENSO, a large-scale climatic fluctuation of the tropical Pacific Ocean). Since 1970, the highest quantities of transatlantic African dust movement have coincided approximately with ENSO events. The current and conservative estimate for the quantity of desert dust that is transported in Earth's atmosphere each year is approximately 2 billion metric tons.[8] Moving in association with this dust are an estimated 2 quadrillion microorganisms.[9]

Declines in the health of Caribbean coral reefs have been attributed to the NAO-related increase in African dust transport to the Americas.[10–12] We have also focused on the potential health effects of dust on terrestrial ecosystems in the Caribbean and southeastern United States.[9] Approximately half of the airborne particles 1- to 2-μm in aerodynamic diameter ($PM_{2.5}$) inhaled in South Florida during the summer months originated in Africa.[1] Equally significant is Asian dust movement in the Pacific Northwest, especially in Alaska and Western Canada. During large Asian dust events, an estimated 4,000 metric tons of soil per hour can affect the Arctic environment.[13] Asian dust can commingle with industrial aerosols from the burgeoning industrial activities in China, Korea, and Japan before crossing the Pacific Ocean. Research conducted in Korea by Park et al.[14] established a correlation between

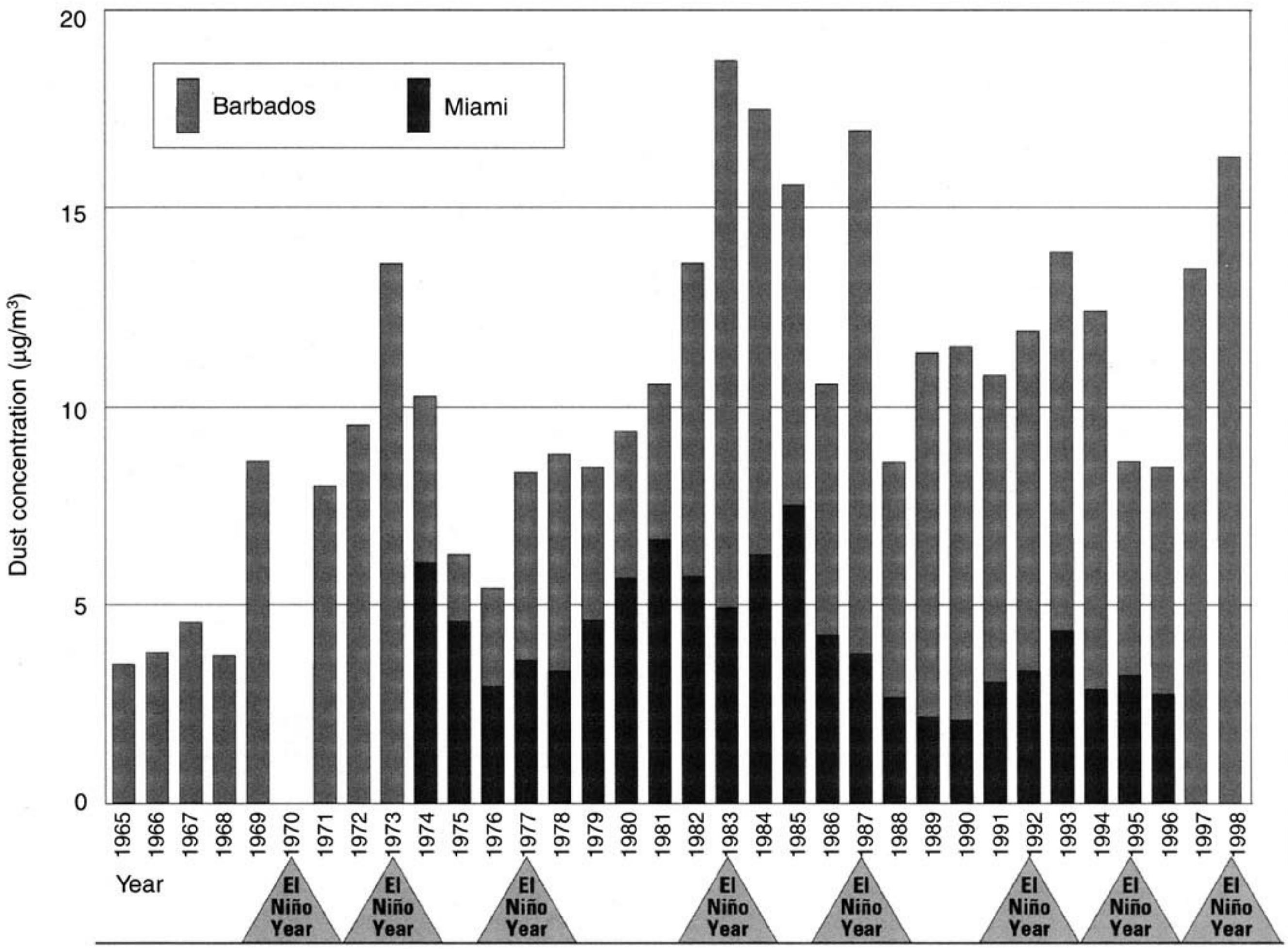

Fig. 1. Average annual flux of Sahelian and Saharan soil dust to Barbados, the Bahamas, and Miami, Florida, 1965–1998. Note the coincidence of African dust flux with the onset of El Niño. (Data courtesy Joseph Prospero, University of Miami. 1997–1998 data for Miami not available.)

dust storms and respiratory-stress–induced apnea. Freye et al.[15] also found an increase in respiratory stress (e.g., asthma, allergic rhinitis, and sinusitis) as a result of higher than normal pollen and fungi counts associated with the ENSO event of 1997–1998 (Fig. 1).

Asthma, a worldwide problem, has increased dramatically in the Caribbean.[16] The Caribbean Asthma Association reported a 17-fold increase in asthma on the island of Barbados since 1973, which corresponds to a prevalence rate of approximately 1 in 4 inhabitants.[17] The resulting increase in the use of asthma medications throughout the Caribbean has had an economic impact on health-care resources.[18] Gyan et al.[19] found a positive correlation between pediatric hospital admissions for respiratory distress in Trinidad and African dust events. This dramatic rise in cases of asthma in the Caribbean parallels the increase in dust flux from Africa to Barbados and Miami (Fig. 1).[1,2]

Anecdotal information from residents of the Caribbean Basin indicates that—in addition to asthma—sinus stress, migraine headache, eye irritation, and chest pain are not uncommon during and after dust events. One study has shown that, once a person is sensitized to an allergen such as fungal spores, even low concentrations can induce an allergic response.[20] In the Middle East, a survey of asthma and allergic rhinitis prevalence identified dust storm exposure as a significant predictor of these illnesses.[21]

In the United States, few people suspect that breathing distress and headache may be caused by exposure to African or Asian dust. Atmospheric dust in the United States often goes unrecognized because the population is accustomed to the hazy conditions caused by anthropogenic emissions. However, the existence of transoceanic dust over the United States is readily apparent in satellite images (Figs. 2–4), which reveal a generalized flux of global dust. Perry et al.[22] found African dust as far north as Maine and as far west as Carlsbad, New Mexico. Approximately half of the dust collected in Carlsbad originated in Africa.

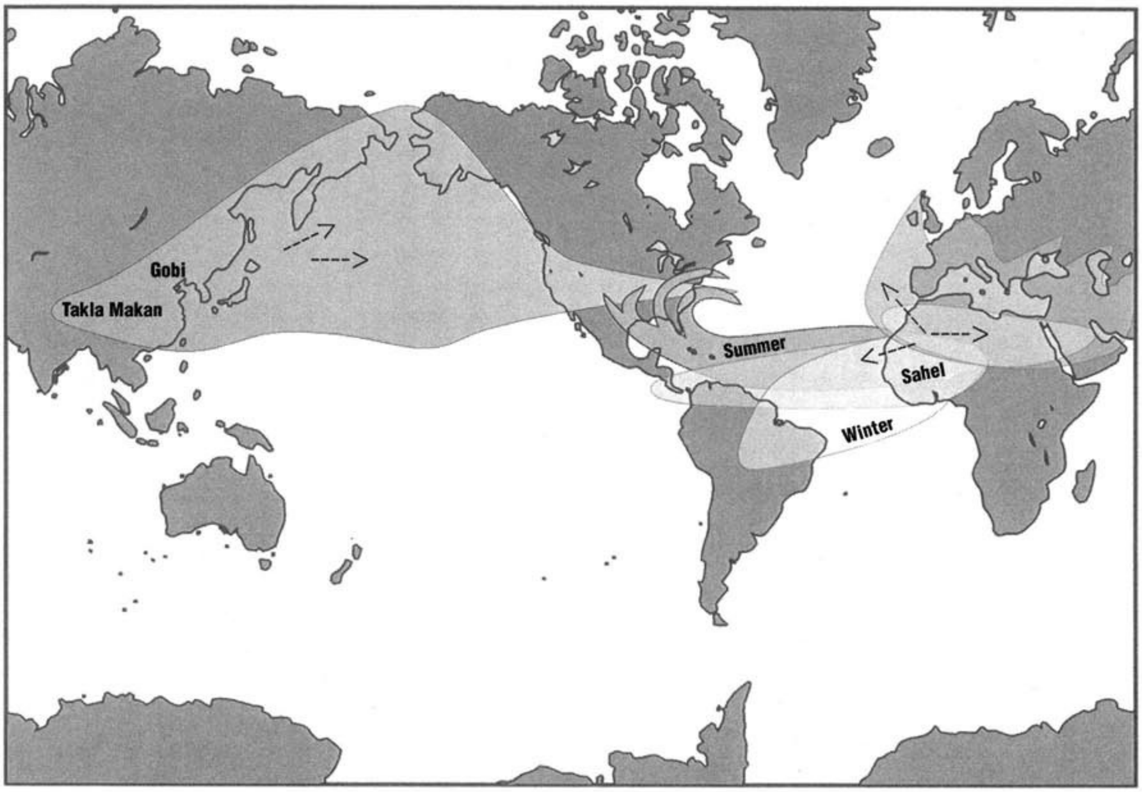

Fig. 2. Generalized flux of dust into the Caribbean and United States. ***Sources:*** **Satellite images and dust sampling data (U.S. Environmental Protection Agency/Nonpoint Source Pollution [EPA/NPS] IMPROVE visibility and particle monitoring program) from Perry et al.[22]; Asian dust flux across the Pacific from Garrison et al.[10]**

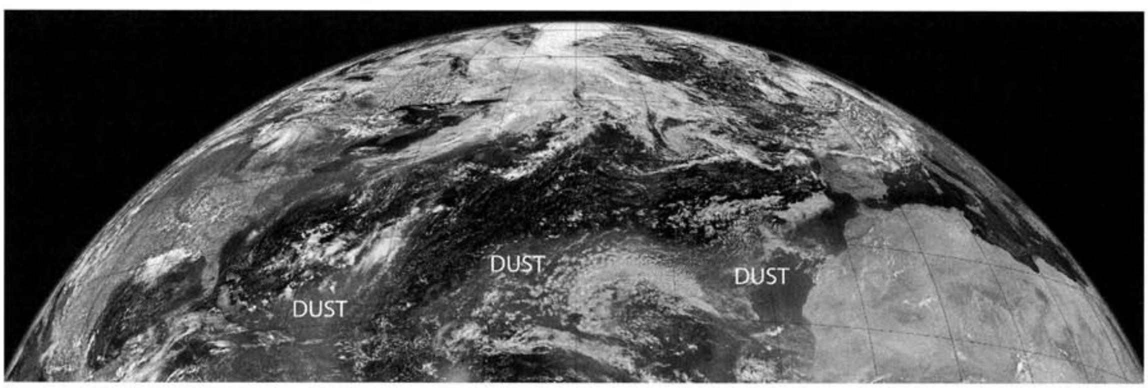

Fig. 3. NASA's SeaWiFS (Sea-Viewing Wide Field-of-View Sensor) satellite image showing African dust clouds traversing the Atlantic. (Information on SeaWiFS is available from <http://seawifs.gsfc.nasa.gov/SEAWIFS.html>)

In 2000, the U.S. Geological Survey (USGS) in St. Petersburg, Florida, began the USGS Global Dust Program (initially funded by the U.S. National Aeronautics and Space Administration [NASA]) to investigate the potential health effects of various African dust components. To date, the major focus has been on the identification of cultivatable microorganisms that are transported along with other organic and inorganic constituents of transoceanic dust clouds. In addition to microbiological testing, dust samples are screened for the presence of heavy metals, pesticides, and radiogenic elements. Preliminary work has shown that arsenic, in association with iron, averages about 20 parts per million (ppm) in African dust particulate matter that reaches South and Central Florida.[23] Analyses of these samples have also shown that concentrations of mercury up to 2 ppm, and concentrations of beryllium and lead isotopes (specifically ^{7}Be and ^{210}Pb), are greater than those found in local rocks and soils.

Our previous microbial study identified numerous

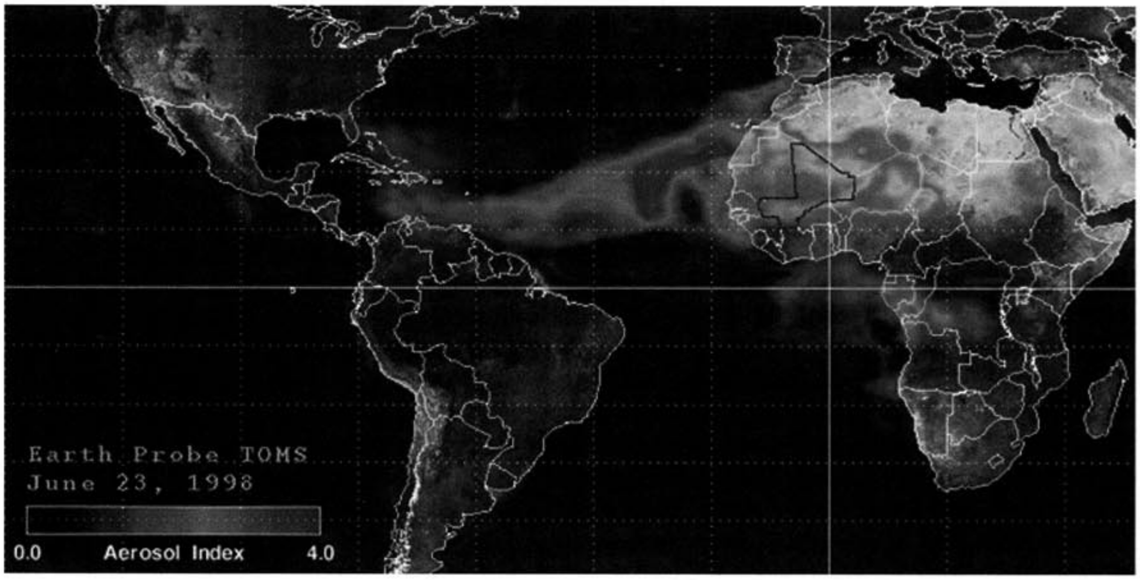

Fig. 4. NASA's Earth Probe TOMS (Total Ozone Mapping Spectrometer) satellite image showing a continuous stream of dust crossing the Atlantic. The North African nation of Mali is outlined in black. (Information on TOMS is available from <http://jwocky.gsfc.nasa.gov>)

species of bacteria and fungi that survive the 5- to 7-day transatlantic transport.[11] The bacteria-to-fungi ratio is variable between dust events, but samples at a site in the U.S. Virgin Islands were usually dominated by bacteria (76% of dust-event isolates).[11] Approximately 30% of the microbes cultured and identified thus far are capable of causing disease in plants and animals, and 10% are opportunistic human pathogens.[11] To date, we have identified fungal species of *Acremonium, Alternaria, Aspergillus, Aureobasidium, Bipolaris, Cladosporium, Coccodinium, Fusarium, Gibberella, Microsporum, Nigrospora, Paecilomyces, Penicillium, Pleospora, Scopulariopsis,* and *Trichophyton*. With the exception of *Pleospora* and *Gibberella* (both of which contain plant pathogens), and *Coccodinium,* all the genera identified include species that are known to cause allergic reactions, pulmonary infections, or skin infections (Table 1).[24,25] These data indicate that any fungus (or spore-forming microorganism) is capable of surviving long-range atmospheric transport, including the common house mold *Stachybotrys chartarum.*

House Mold and the Potential Dust Connection

An eyewitness to the 1930 American Dust Bowl event stated:

> *Since breathing is unpleasant even indoors while a dust storm is at its height, people sought relief through wearing wet cloths over their faces.... But the practice soon proved to be a dangerous one.... The constant breathing of damp air, aggravated by the dust, frequently led to pneumonia, with many deaths resulting....The dust I had labored in all day began to show its effects on my system. My head ached, my stomach was upset, and my lungs were oppressed and felt as if they must contain a ton of fine dirt.*
>
> —Lawrence Svobida, *An Empire of Dust*[27]

The adverse health effects of molds in homes—and the associated multibillion-dollar home insurance crisis—began in the 1970s and are well documented by other contributors to this, and the previous,[28] *Archives of Environmental Health* special issues on molds and mycotoxins. Precise causes of the mold problem are difficult to discern, as indicated by the increase in litigation associated with mold-related insurance claims.[29] In general, the causes can be linked with changes in home and office construction methods, materials, and design, and with the increasing dependence on central air conditioning. Air conditioning not only reduces the circulation of fresh air within a dwelling, but also induces thermal gradients within homes and offices that create localized cool and moist areas conducive to mold growth.[30] In addition, the porous ducting materials increasingly used in central air conditioning systems create a favorable culture medium for microbes when cool and damp.[31,32] The dark and cryptic conditions in the air conditioning ducts and elevator shafts of large buildings are notorious promoters of mold growth.[33,34]

The most frequently mentioned cause of house mold is flooding, especially in homes with gypsum and cardboard interior sheetrock walls. After flood water recedes, mold can grow unseen on standard wooden studs and in porous insulating materials between wall panels.[35] Detection of such mold is difficult, often requiring costly dismantling of structures. The health

Table 1.—Fungal Species Capable of Affecting Humans and Plants, Cultured and Identified in Samples of Atmospheric Desert Dust

Genus	Pathogen type[24,25]	Distribution[24,26]	Disease potential[24,25]
Acremonium	Human	Wide distribution. Common in soil, on plants, and indoors.	Mycetoma (colonization of tissue/bone), onychomycosis (colonization of nail), mycotic keratitis, allergen. Can cause a number of different disease types in immunocompromised individuals.
Alternaria	Human and plant	Wide distribution. Common in soil, on plants, and indoors.	Cutaneous phaeohyphomycosis (colonization of skin), potent allergen (common cause of extrinsic asthma). Can cause deep tissue infections in immunocompromised individuals.
Aspergillus	Human, animal, and insect	Wide distribution. Common in soil, organic detritus, and indoors.	Aspergilliosis (pulmonary [allergic and colonizing], disseminated, central nervous system, cutaneous, nasal–orbital, and iatrogenic), potent allergen. Causes a number of different disease types in immunocompromised individuals.
Aureobasidi-	Human and plant	Found in temperate areas. Common on plant tissue and indoors.	Cutaneous phaeohyphomycosis, invasive disease in immunocompromised individuals.
Bipolaris	Human and plant	Wide distribution. Common on plants and indoors.	Pansinusitis, meningoencephalitis, chronic pulmonary disease.
Cladosporium	Human and plant	Wide distribution. Most commonly isolated fungi in outdoor studies.	Cutaneous phaeohyphomycosis, chromoblastomycosis (subcutaneous skin infections), mycotic keratitis, potent allergen.
Coccodinium	Unknown	Found in tropical air samples.[11]	No information.
Fusarium	Human and plant	Wide distribution. Common isolate in soil and indoors.	Invasive cutaneous infection (erythematous lesions and nodules), systemic granulamatous disease, allergen.
Gibberella	Plant	Wide distribution.	Stalk rot, corn ear rot, Bakanae disease.
Microsporum	Human and animal	Wide distribution.	Dermatophytosis (i.e., ringworm).
Nigrospora	Human	Wide distribution. Common in soil, organic detritus, and indoors.	Allergen.
Pae-	Human and insect	Wide distribution. Common in soil, organic detritus, and indoors.	Mycotic keratitis paecilomycosis , pneumonia, allergen.
Penicillium	Human	Wide distribution. Very common in temperate regions. Common in soils and indoors.	Bronchopulmonary penicilliosis, potent allergen (hypersensitivity and allergic alveolitis).
Pleospora	Plant	Wide distribution.	Leaf spot. Species can produce mycotoxins toxic to certain plants (e.g., the opium poppy).
Scopulariopsis	Human and insect	Wide distribution. Common in soils and indoors.	Pneumonia in immunocompromised individuals, rare subcutaneous and pulmonary cases, associated with Type III allergy.
Trichophyton	Human and animal	Wide distribution. Common in soils and indoors.	Dermatophytosis, allergen.

problems associated with house mold have spawned high-tech mold detection and litigation industries, including a new cottage industry that uses specially trained dogs. Although no single source of fungi is implicated in the house mold problem, it is possible that fungal spores transported in desert dust may affect indoor human health both directly (by initiating an allergic response) and indirectly (as seed for indoor growth of mold). This relationship may be especially true in areas around the globe where desert dust settles and accumulates in warm and damp climates, such as the southeastern United States.

Although molds identified in houses, and in African dust samples, are also common in U.S. soils, it is suspected that microbes that survive transoceanic transport and exposure to ultraviolet radiation—as well as their

hot and arid sources—may be more capable of withstanding extreme conditions than native species.[36] The study of airborne fungi and bacteria was initiated in the late 19th century and was later considered important for understanding the worldwide spread of rust fungi in agricultural crops during the 1930s.[37–39] The availability of new technologies (e.g., the polymerase chain reaction test), combined with agricultural and human security issues, are driving a revival in studies of aerobiology and the various pathways through which microbes can spread across the planet. Our atmospheric microbiology research group—one of the few in the United States—is expanding its activities, and we hope to contribute to a better understanding of both the causes and prevention of human and plant disease epidemics.

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References

1. Prospero JM. Long-term measurements of the transport of African mineral dust to the southeastern United States: implications for regional air quality. J Geophys Res 1999; 104(D13):15917–27.
2. Jaffe D, McKendry I, Anderson T, et al. Six "new" episodes of trans-Pacific transport of air pollutants. Atmos Environ 2003; 37(3):391–404.
3. Middleton NJ. A geography of dust storms in southwest Asia. J Climatol 1986; 6(2):183–96.
4. Prospero JM, Lamb PJ. African droughts and dust transport to the Caribbean: climate change implications. Science 2003; 302(5647):1024–27.
5. Prospero JM, Nees RT. Dust concentration in the atmosphere of the Equatorial North Atlantic: possible relationship to the Sahelian drought. Science 1977; 196:1196–98.
6. Prospero JM, Nees RT. Impact of the North African drought and El Niño on mineral dust in the Barbados trade winds. Nature 1986; 320(6064):735–38.
7. Moulin C, Lambert CE, Dulac F, et al. Control of atmospheric export of dust from North Africa by the North Atlantic Oscillation. Nature 1997; 387:691–94.
8. Perkins S. Dust, the thermostat. Sci News 2001; 160: 200–01.
9. Griffin DW, Kellogg CA, Garrison VA, et al. The global transport of dust. Amer Sci 2002; 90(3):228–35.
10. Garrison VH, Shinn EA, Foreman WT, et al. African and Asian dust: from desert soils to coral reefs. Bioscience 2003; 53:469–80.
11. Griffin DW, Garrison VH, Herman JR, et al. African desert dust in the Caribbean atmosphere: microbiology and public health. Aerobiologia 2001; 17(3):203–13.
12. Shinn EA, Smith GW, Prospero JM, et al. African dust and the demise of Caribbean coral reefs. Geophys Res Let 2000; 27(19):3029–32.
13. Rahn KA, Boyrs RD, Shaw GE, et al. Long-range impact of desert aerosol on atmospheric chemistry: two examples. In: Fenner F (Ed). Saharan Dust: Mobilization, Transport, and Deposition. Chichester, U.K.: John Wiley & Sons, 1977; 243–66.
14. Park J-W, Lim YH, Kyung SY, et al. Effects of Asian dust events on peak expiratory flow and respiratory symptoms in subjects with bronchial asthma. Eur Respir J 2003; 22 (45):S301.
15. Freye HB, King J, Litwin CM. Variations of pollen and mold concentrations in 1998 during the strong El Niño event of 1997–1998 and their impact on clinical exacerbations of allergic rhinitis, asthma, and sinusitis. Allergy Asthma Proc 2001; 22(4):239–47.
16. Monteil MA, Juman S, Hassanally R, et al. Descriptive epidemiology of asthma in Trinidad, West Indies. J Asthma 2000; 37(8):677–84.
17. Howitt ME. Asthma management in the Caribbean—an update. Postgrad Doctor—Caribbean 2000; 16(2):86–104.
18. Howitt ME, Naidu R. The economics of asthma treatment in Barbados—a review of the drug cost. West Indian Med J 2000; 49(2):19.
19. Gyan K, Henry W, Lacaille S, et al. African dust clouds are associated with increased paediatric asthma Accident and Emergency admissions on the Caribbean island of Trinidad. Lancet 2002. <www.thelancet.com/era/search?searchtext=african+dust&search.x=39&search.y=6>
20. Gravesen S. Fungi as a cause of allergic disease. Allergy 1979; 34:135–54.
21. Bener A, Abdulrazzaq YM, Al-Mutawwa J, et al. Genetic and environmental factors associated with asthma. Hum Biol 1996; 68(3):405–14.
22. Perry KD, Cahill TA, Eldred RA, et al. Long-range transport of North African dust to the eastern United States. J Geophys Res 1997; 102:11225–38.
23. Holmes CW, Miller R. Atmospherically transported metals and deposition in the southeastern United States: local or transoceanic? Appl Geochem 2003 (forthcoming).
24. St-Germain G, Summerbell R. Identifying Filamentous Fungi. Belmont, CA: Star Publishing, 1996.
25. Rippon JW. Medical Mycology: The Pathogenic Fungi and the Pathogenic Actinomycetes, 3rd ed. Philadelphia, PA: W.B. Saunders, 1988.
26. Ren P, Jankun TM, Belanger K, et al. The relation between fungal propagules in indoor air and home characteristics. Allergy 2001; 56:419–24.
27. Svobida L. An Empire of Dust. Caldwell, ID: Caxton Printers, 1940.
28. Molds and mycotoxins: special issue, Pt 1. Arch Environ Health 2003 Jul; 58(7):385–448.
29. Dotzour MG, Bravenec E. Insurance at a premium: Tierra Grande 2002; 9(2).
30. Eggleston PA. Environmental control for fungal allergen exposure. Curr Allergy Asthma Rep 2003; 3(5):424–29.
31. Ezeonu IM, Noble JA, Simmons RB, et al. Effect of relative humidity on fungal colonization of fiberglass insulation. Appl Environ Microbiol 1994; 60(6):2149–51.
32. Foarde KK, Menetrez MY. Evaluating the potential efficacy of three antifungal sealants of duct liner and galvanized steel as used in HVAC systems. J Ind Microbiol Biotechnol 2002; 29(1):38–43.
33. Samson RA. Occurrence of moulds in modern living and working environments. Eur J Epidemiol 1985; 1(1):54–61.
34. Lutz BD, Jin J, Rinaldi MG, et al. Outbreak of invasive *As-*

pergillus infection in surgical patients, associated with a contaminated air-handling system. Clin Infect Dis 2003; 37(6):786–93.
35. U.S. Environmental Protection Agency (EPA), Office of Radiation and Indoor Air (6609J). Flood cleanup—avoiding indoor air quality problems. Washington, DC: Indoor Air Quality Information Clearinghouse, 2003; EPA Publication No. 402-F-93-005.
36. Imshenetsky AA, Lysenko SV, Kozlova TM, et al. Resistance of mesospheric microorganisms to periodic freezing—thawing. Mikrobiologiia 1983; 52(6):902–08.
37. Bowden J, Gregory PH, Johnson CG. Possible wind transport of coffee rust across the Atlantic Ocean. Nature 1971; 229:500–01.
38. Nagarajan S, Singh DV. Long-distance dispersion of rust pathogens. Annu Rev Phytopathol 1990; 28:139–53.
39. Meier FC, Lindbergh CA. Collecting microorganisms in the arctic atmosphere. Arctic Monthly 1935; 40:5–20.